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Fundamental parameters for the eclipsing binary AzV 73 in the Small Magellanic Cloud

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Abstract. A CCD V light curve for the eclipsing binary star AzV 73 is presented. This new photometric observations are analysed together with previously published CCD I photometry from Udalski et al. (1998) and spectrographic data from Niemela & Bassino (1994), by means of the Wilson-Devinney code. It is found that this system is semi-detached, with an orbital inclination of roughly 86° and a separation of 42 $R_{\odot}$. The sizes and masses are $R_1 = 11.53 \pm 0.5\ R_{\odot}$, $M_1 = 25.26 \pm 0.7\ M_{\odot}$, and $R_2 = 15.46 \pm 0.4\ R_{\odot}$, $M_2 = 21.96 \pm 0.8\ M_{\odot}$ for the primary and secondary components, respectively.

Key words. binaries: eclipsing – stars: early-type – stars: fundamental parameters – stars: individual: AzV 73

1. Introduction

Although the history of the study of eclipsing binaries in the Magellanic Clouds is almost a century old the acquisition and analysis of high quality data is today of great interest since of (i) it provides valuable data on the fundamental parameters needed for the physical modelling of stars and (ii) well studied binaries are potentially good standard candles.

The amount of Magellanic eclipsing systems with precise and complete light curves determined has been continuously increased during the last years, mainly as a subproduct of the microlensing experiments such as MACHO (Alcock et al. 1997), OGLE (Udalski et al. 1998) and EROS (Grison et al. 1995). Nevertheless, the number of systems with available radial velocity curves is still small, since such observations require large telescopes due to the faintness of these stars. This situation is stressed in the Small Magellanic Cloud, because of its greater distance modulus. However, one of the SMC binaries with published radial velocity curve, AzV 73 ($\alpha = 0^{\rm h}50^{\rm m}28^{\rm s}, \delta = -73°03'15''$ J2000), did not have a published light curve analysis up to now.

AzV 73 appears immersed in the H II region DEM S51 (Davies et al. 1976). Its light variability was discovered by H. H. Swope on photographic plates taken by Yale for Columbia (Shapley & McKibben Nail 1953). They recognized the star as an eclipsing binary and gave a period of $4\overset{\rm d}{.}6068$.

This star is the object 33 of the photographic UBV survey of the SMC core performed by Basinski et al. (1967). They derived the following magnitudes and colours: $V = 14.2$, $(B-V) = -0.29$ and $(U-B) = -0.94$.

Azzopardi & Vigneau (1975) classified this star as B0 in their objective-prism survey. From that work comes the denomination of AzV 73. Later on, Isserstedt (1978) performed UBV photoelectric photometry for this star. According his data, obtained with the 61-cm telescope of the Bochum University at La Silla, Chile, he derives $V = 14.08$:, $(B-V) = -0.17$: and $(U-B) = -0.91$.

The spectroscopic orbit of AzV 73 was published by Niemela & Bassino (1994). They classified the components of the system as O9 V+B0 III, and derived fundamental parameters for the system, assuming an inclination close to 90°.

More recently, Massey et al. (1995) classified this star as O8.5 V and Cornett et al. (1997) published far UV photometry, and derived a value for the reddening.

AzV 73 has a complete I light curve together with some observations in the V and B bands obtained with the 1.3-m Warsaw telescope at Las Campanas, in the course of the OGLE microlensing search program (object 202153 in SMC_SC5 in the OGLE catalog). From these CCD observations, Udalski et al. (1998) derive $I = 14.268$, $(B-V) = -0.215$ and $(V-I) = -0.150$. They also determined an ephemeris.

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Table 1. Observing logs.

date	1995, Oct. 21–25	1997, Nov. 15–21	1998, Dec. 4–8	1999, Nov. 17–22	2000, Nov. 11–16
HJD-2450000	0011–0016	0767–0774	1151–1156	1499–1505	1859–1865
images acquired	$44 \times V$	$4 \times B + 4 \times R + 37 \times V$	$11 \times V$	$29 \times V$	$25 \times V$
range of exp. times [s]	60–300	60–240	30–300	60–240	60–120

2. Data acquisition and photometry

2.1. Observations and reductions

The CCD V images analysed here in were obtained along five observing runs with the 2.15-m telescope at CASLEO, from 1995 to 2000. Table 1 resumes the data obtained in each observing season. The fields are circular, of $\sim 9'$ diameter. Technical characteristics of the CCD and instrumental configuration can be found in the first work of this campaign, Ostrov et al. (2000).

Images were corrected for instrumental signatures in the usual manner (bias-trimming, zero subtraction, flat-field) using the standard IRAF[1] CCD processing packages.

2.2. Relative photometry

Light contamination from faint neighbour stars can be significant for plain aperture photometry in SMC fields, where the crowding is significant. For this reason, we carefully scrutinised the immediate neighbourhood of AzV 73 to find faint stars whose light could contaminate the aperture photometry measurements. The more notorious neighbour, a faint star that can be seen located at some $6.5''$ from it towards the nor-west in Fig. 1, is some 2.6 mag fainter than AzV 73. Its effect on the measured magnitude for AzV 73 is less than 0.01 mag in the frames with better seeing, but it can rise up 0.03 mag for the worse seeing images. Therefore, in order to obtain precise photometry avoiding the light contamination from neighbouring stars, we performed simultaneous profile fitting photometry by means of the DAOPHOT II-ALLSTAR-ALLFRAME programs (Stetson 1987, 1991).

To obtain relative photometry of AzV 73 we selected a group of 25 field stars to be used as local standards. We used these stars to derive the zeropoint offsets between the instrumental system of each frame, and then we tied all the measurements to an unique synthetic system.

In view of the profile errors being significant in our undersampled images ($0\overset{''}{.}813$/pixel), to perform the photometry we explore the following methods:

1. plain aperture photometry;
2. plain profile fitting photometry;
3. aperture photometry after subtraction of the stellar neighbours inside the object apertures;
4. aperture photometry after subtraction of the stellar neighbours inside the object apertures and sky annulus.

We found that, for these images, the profile fitting photometry yielded the best results.

2.3. Absolute photometry

To obtain absolute photometry we acquired some B frames of the field of AzV 73 during the night of Nov. 15, 1997, and some R frames during Nov. 20, 1997. Standard stars of the Selected Areas 92 and 98 from Landolt (1992) where also observed during both nights. Unfortunately, the analysis of the residuals of the transformation equations revealed that the night of Nov. 15 was not of photometric quality. We discarded one whole set of standard stars observations and achieved an acceptable fit, with an RMS of 0.020 mag for B and 0.010 mag for V. With the aim of verifying the photometric stability along this night, we examined the behaviour of the "local standards" in the field of AzV 73. This suggested that the night of Nov. 15 (at least at the moment of acquiring the B frames of AzV 73) was still profitable for absolute photometry, although our $(B{-}V)$ value must be considered with caution.

Our measurements, normalized to phase 0.75 gave $V = 14.049$: and $(B - V) = -0.131$: For the night of Nov. 20 the RMS residuals of our derived transformation equations were 0.007 mag for V and 0.006 mag for R. The magnitude and colour for AzV 73 (for phase 0.75) were $V = 14.081 \pm 0.02$ and $V - R = -0.075 \pm 0.02$.

A Table containing the final standard magnitudes derived for AzV 73, as well as the internal RMS residuals derived from the local calibrators, the airmass and the FWHM for each frame, will be available in electronic form.

3. Data analysis

3.1. Ephemeris

Given that Shapley & McKibben Nail (1953) did not publish times of minima but only a period estimate, and due to our relatively short time base, we are not able to improve their period for more than a decimal (the observation dates of the OGLE project are enconpassed by our observing runs). From our light curve, we derived a period of $4\overset{d}{.}60675 \pm 0.0001$, which is in agreement with that of Udalski et al. (1998), who obtained $P = 4\overset{d}{.}60677$.

[1] IRAF software is distributed by NOAO, operated by AURA for NSF.

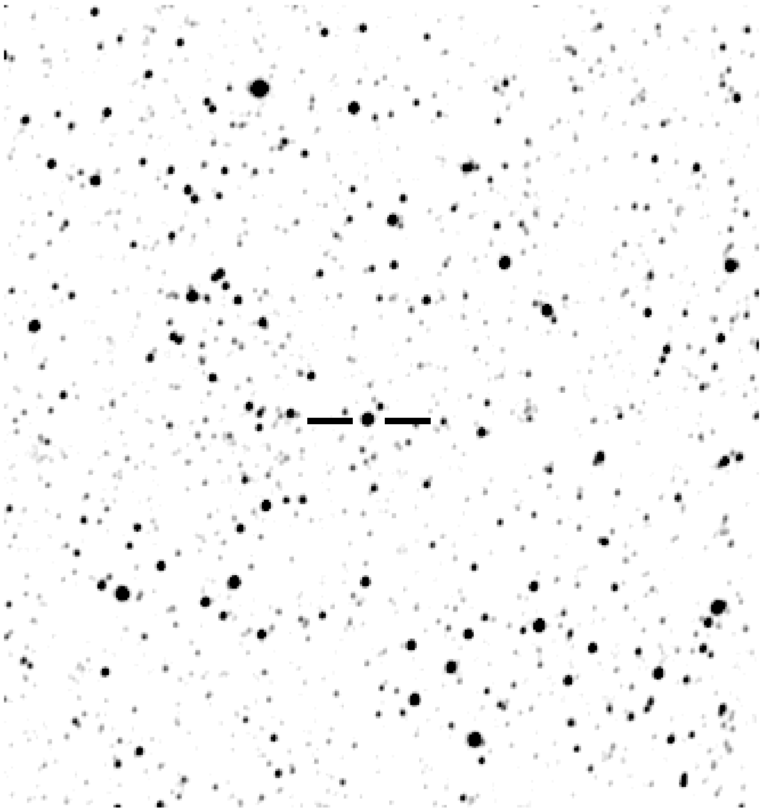

Fig. 1. The field of AzV 73. North is at the top and East is at the left. The size of the region displayed is approximately $5' \times 5'$.

We observed two minima, during the 1997 and 1999 runs, at HJD = 2450767.596 ± 0.01 and HJD = 2451504.676 ± 0.01. From our overall analysis with the WD code, including the radial velocities from Niemela & Bassino (1994), we obtained P = $4\overset{\mathrm{d}}{.}606757$, in agreement with the photometric period.

3.2. Light and radial velocity curve solutions

The V light curve presented here in was analysed with the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1990; Wilson 1993), jointly with the I light curve from Udalski et al. (1998) and the spectrographic observations from Niemela & Bassino (1994). The V observations from the OGLE project (36 data points) were not included since they are noisier than ours. Based on its spectral type, a temperature of 33 000 K was assigned to the primary component of AzV 73, following Schmidt-Kaler (1982). Gravity-darkening exponents as well as bolometric albedos were fixed at their theoretical values for radiative atmospheres (Lucy 1976; Rucinski 1969). Limb-darkening coefficients were taken from Díaz-Cordovéz et al. (1995). Both stars were assumed to rotate sinchronously. The time of minimum and period quoted in the previous section were used.

The following parameters were adjusted: the semi-major axis a, the systemic velocity V_γ, the mass ratio $q = m_2/m_1$, the orbital inclination i, the temperature and relative luminosity of the secondary component T_2 and L_2 and the surface potentials of both stars Ω_1 and Ω_2. These were grouped in two subsets, the one containing a, V_γ and q and the other containing i, T_2, Ω_1, Ω_2 and L_2. In the first step, a V_γ and q were fitted using only the radial velocity data and assuming an inclination of 90°, as it is suggested by the deep primary eclipse. Then, these values were kept fixed and the second parameter set were adjusted using only the light curve. This procedure was repeated iteratively until the solution converged, then all the parameters were allowed to be fitted simultaneously using both radial velocities and photometric data.

The inspection of the observed light curves shows that the maximum following the primary minimum is slightly brighter than the other (O'Connell effect, see Davidge & Milone 1987). This feature was modelled placing a hot spot on one of the stars, to avoid difficulties with convergence. Also other slight systematic deviations from the modelled curves can be noted, particularly a shortage of light just before the beginning of the main eclipse, probably due to circumstellar matter (notice that this feature is present in both light curves, suggesting that it is not a product of photometric errors).

We found that there are two possible solutions that fit well the observations. The one yielding $R_1 = 11.5\ R_\odot$ and $R_2 = 15.5\ R_\odot$, corresponding to a semidetached configuration, with the cooler, less massive star filling its Roche-lobe. The other solution yielding $R_1 = 13.7\ R_\odot$

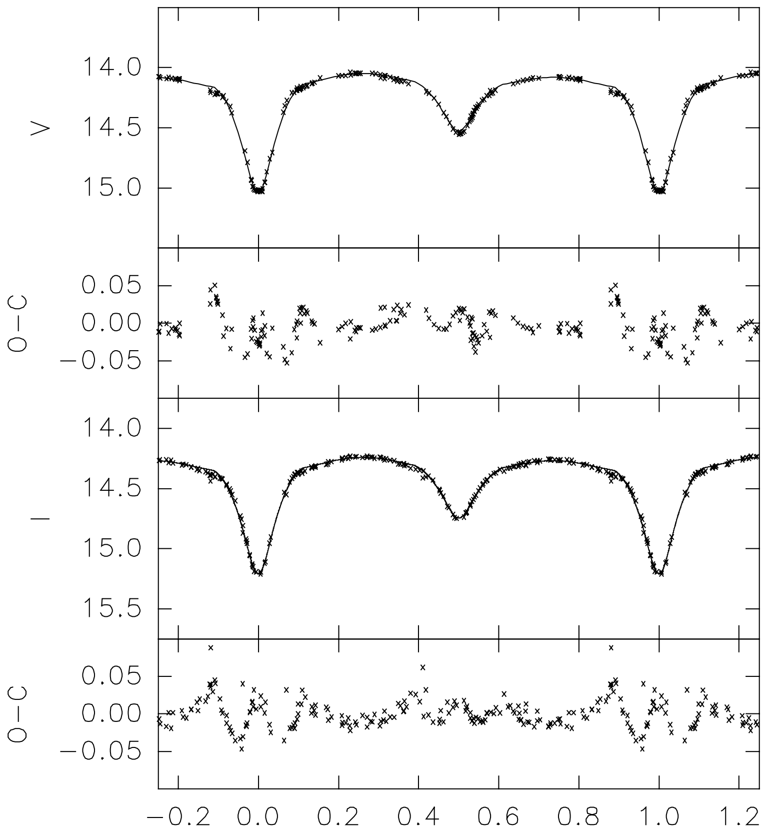

Fig. 2. Observed and modelled light curves for AzV 73 and their concomitant (O–C) residuals.

and $R_2 = 13.1\ R_\odot$, with the two stars inside their respective Roche-lobes, conforming a detached system.

Although in their previous study Niemela & Bassino (1994) suggested that this could be an unevolved system, we believe that the semidetached configuration is the one correct. On one hand, the spectral types given by Niemela & Bassino, with the more massive star being O9 V and the less massive one being B0 III, suggest that the less massive component should be the bigger one. On the other hand, an even more important fact is that, if we trust this spectral classification, being the less massive star the more evolved one, we must conclude that mass inversion occurred in this system and the present configuration must be that of a typical semidetached binary, with the secondary, less massive star filling its Roche-lobe.

Therefore, we adopt the semidetached configuration as the one that characterizes the better this system. The parameters of the model are listed in Table 2 and the computed values for radii, masses, bolometric magnitudes and surface gravities are displayed in Table 3.

Figures 2 and 3 display the observed and modelled light and velocity curves respectively, together with the O–C residuals.

Table 2. Model parameters

a	$42.07 \pm 0.5\, R_\odot$
V_γ	$146.0 \pm 3\,\mathrm{km\ s}^{-1}$
i	$85.6 \pm 0.5°$
q (M_2/M_1)	0.87 ± 0.03
T_1	$33\,000 \sim 37\,000$ K (adopted)
Ω_1	4.566 ± 0.07
g_1	1.00 (adopted)
A_1	1.00 (adopted)
T_2	$23\,630 \sim 27\,130$ K[a]
Ω_2	3.535 ± 0.12
g_2	1.00 (adopted)
A_2	1.00 (adopted)
Hot spot (in star 1):	
colatitude	90°
longitude	270°
angular radius	86°
temp. factor	1.03

[a] Values for T_2 resulting for the above quoted values adopted for T_1, respectively.

4. Discussion

According with the spectral types and masses this system must have experienced class A mass exchange, being now the more massive star that originally less massive. However, it is expected that the mass gainer should be similar to stars that have evolved isolately in all aspects

Table 3. Star dimensions

M_1	$25.26 \pm 0.7\ M_\odot$
R_1	$11.53 \pm 0.5\ R_\odot$
$M_{\rm bol}$ 1	$-8.09\sim-8.59$ [a]
$\log g_1$[cgs]	3.72 ± 0.06
M_2	$21.96 \pm 0.8\ M_\odot$
R_2	$15.46 \pm 0.4\ R_\odot$
$M_{\rm bol}$ 2	$-7.28\sim-7.88$ [a]
$\log g_2$[cgs]	3.40 ± 0.03

[a] The range in the derived bolometric magnitudes corresponds to the range in the values adopted for T_1.

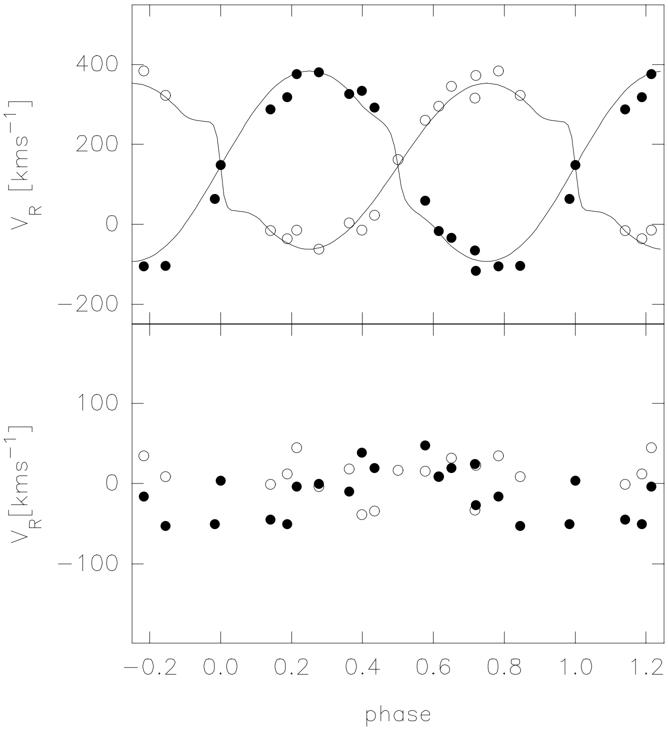

Fig. 3. Top: Observed and modelled radial velocity curve for AzV 73. Bottom: (O–C) residuals for the radial velocities. Hollow circles correspond to the primary component and filled ones stand for the secondary.

excepting age (Vanbeveren 1998), hence masses and radii of the primary can be used to check the predictions of single star models, at least until detailed evolutive models of exchanging mass stars be available.

The mass and radius of the primary component of AzV 73 are in good agreement with the models of Charbonell et al. (1993). From they evolutive tracks for $Z = 0.004$, we found that a star having originally 25 $M_\odot$ will have a mass of 24.7 $M_\odot$, a radius of 11.15 $R_\odot$ and an effective temperature of 33 500 K after 6.22 Myr.

Regarding the distance modulus, the main problems are the uncertainty in the temperature scale, accentuated in the SMC because of the low metallicity, and the reddening. If we adopt a total $(B-V)_0 = -0.28$ for the system based on its spectral types, then we derive a colour excess of $E(B-V) = 0.149$, although it must be recalled that our $(B-V)$ photometry is doubtful.

Since R has different values in the galaxy (3.1, Howarth 1983) and the SMC (2.7, Bouchet et al. 1985), we need to distinguish how much reddening is foreground or intrinsic to the SMC. We adopt as foreground reddening $E(B-V) = 0.07$ (Larsen et al. 2000), hence being the SMC intrinsic colour excess $E(B-V) \sim 0.08$ for AzV 73. With these values, we derived a distance modulus of $(m-M)_0 = 19.19$ to 19.52 mag using the temperature scale of Schmidt-Kaler (1982) or Chlebowsky & Garmany (1991), respectively. The first value agrees with that of Massey et al. (1995)(19.1 $\pm$ 0.3 mag), but an error of 0.05 mag in our $(B-V)$ value would produce a difference of $\sim$0.15 mag in the absorption estimation. In fact, our reddening value is substantially higher than that given by Cornett et al. (1997), who derived an SMC colour excess of $E(B-V) = 0.04$ mag for AzV 73, adopting a foreground reddening of only 0.02 mag. Therefore, our distance modulus must be considered only as a coarse approximation. Indeed, the $(B-V)$ obtained by Udalski et al. (1998), -0.215 ± 0.03, seems to point to this lower reddening, although the residuals of their V observations are higher than its nominal errors.

5. Summary

AzV 73 is an eclipsing system composed by two stars with masses of $25.26 \pm 0.7\ M_\odot$ and $21.96 \pm 0.8\ M_\odot$ and radii of $11.53 \pm 0.5\ R_\odot$ and $15.46 \pm 0.4\ R_\odot$ respectively, conforming a semidetached system with the cooler, bigger and less massive star filling its Roche-lobe.

We found a good agreement between our derived physical parameters for the mass gainer and those predicted by the evolutionary models for stars with SMC metallicities (Charbonell et al. 1993), although a more definitive comparison would be made with systems that have not experienced mass exchange.

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